FINAL REPORT:

Functional Requirements and Performance Specifications for Avian Radar Systems

Project RC-200723

Integration and Validation of Avian Radars (IVAR)

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14. ABSTRACT
The Integration and Validation of Avian Radars (IVAR) project identified a set of functions a modern avian radar system should be capable of performing and developed specifications for the level at which these functions have been demonstrated to perform with existing commercial-off-the-shelf (COTS) technology. Those functions and specifications are presented in this document and are based on the capabilities of the avian radar systems evaluated by the IVAR project staff under actual field conditions at military installations using live-feed and recorded data. The IVAR staff has endeavored to frame these capabilities as vendor-neutral specifications so they can serve as a baseline to which additional functions, or better performance of existing functions, can be added from other avian radar systems or from new systems as they come on the market.

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Executive Summary

The Integration and Validation of Avian Radars project (IVAR; Brand, 2011) identified a set of functions a modern avian radar system should be capable of performing. It also developed specifications for the level at which these functions have been demonstrated to perform with existing commercial-off-the-shelf (COTS) technology. Those functions and specifications are presented in this document, with the goal of using them as a starting point for anyone interested in acquiring and deploying avian radar technology.

The functional requirements and performance specifications presented here are based on the capabilities of the avian radar systems evaluated by the IVAR project staff under actual field conditions using live-feed and recorded data. The IVAR staff has endeavored to frame these capabilities as vendor-neutral specifications so they can serve as a baseline to which additional functions, or better performance of existing functions, can be added from other avian radar systems or from new systems as they come on the market.

While the IVAR project focused its studies on applications for avian radar technology at US Department of Defense (DOD) facilities, the IVAR team worked closely with a similar project carried out by the Center of Excellence for Airport Technology (CEAT) at the University of Illinois. The CEAT project was funded by the US Federal Aviation Administration (FAA) to evaluate civilian applications for this same technology. Thus, we anticipate that the majority of the functions and specifications for avian radar systems outlined in this document will be useful for both military and civilian applications.

The IVAR project demonstrated that the COTS avian radar systems it evaluated:

- Coupled conventional marine radars with sophisticated digital processors to create systems that are capable of being operated unattended 24/7/365, under a broad range of environmental conditions and for a variety of potential applications;
- Automatically and continuously detect and track hundreds of birds of all sizes, in real-time, in three spatial dimensions, through 360° of azimuth, and for the larger birds, at ranges of >11 km (6 nautical miles) and altitudes of >1 km (3300 feet);
- Continuously record a range of measurement data that include location, altitude, time, speed, heading, intensity, and other parameters for each target during each scan of the radar;
- Are network-capable and can stream large volumes of the plots (detections) and track data in real-time, securely across local-area (e.g., facility) and wide-area (e.g., the Internet) networks, without errors and with high network availability, to remote data servers for redistribution to other workstations and to store and retrieve data for further analysis.

- Can integrate tracks from widely separated radars and fuse tracks from radars with overlapping coverages into a common operational picture (COP) in real-time with a high degree of spatial and temporal alignment, thereby providing increased track continuity through space and time.

List of Acronyms

Acronym	Definition
3G	Third Generation
AC	Alternative Current
AGL	Above Ground Level
ASCII	American Standard Code for Information Interchange
CAT5	Category 5 Cable
CEAT	Center of Excellence for Airport Technology
CFAR	Constant False Alarm Rate
COP	Common Operational (or Operating) Picture
COTS	Commercial Off-The-Shelf
DC	Direct Current
DIACAP	DoD Information Assurance Certification and Accreditation Process
DOD	[US] Department of Defense
RDP	Radar Digital Processor
FAA	[US] Federal Aviation Administration
GIS	Geographic Information System
GMT	Greenwich Mean Time; see also UTC
GPS	Global Positioning System
GUI	Graphical User Interface
IVAR	Integration and Validation of Avian Radars
KML	Keyhole Markup Language
LAN	Local-Area Network
MTBF	Mean Time Between Failures
NTP	Network Time Protocol
PPI	Plan Position Indicator
RST	Radar Sensor Transceiver
RW	Remote Workstation
TB	Terabyte
TCP/IP	Transmission Control Protocol/Internet Protocol
UAV	Unmanned Aerial Vehicle
UI	User Interface
UTC	Coordinated Universal Time
VPN	Virtual Private Network
WAN	Wide Area Network
WiFi	Wireless Fidelity
WGS84	World Geodetic System, 1984 Revision

1. Introduction

This document is an addendum to the Integration and Validation of Avian Radars (IVAR) project Final Report (Brand 2010).

During the course of the IVAR project, the team members identified functions they thought a modern avian radar system should be capable of performing. The staff also measured or collected specifications for the level at which these systems should perform these required functions. This document presents those functional requirements and performance specifications, with the goal of providing them as a starting point for anyone who is interested in acquiring and using avian radar technology.

The functional requirements and performance specifications provided in this document are based on the capabilities of the avian radar systems the IVAR project evaluated during its three-year study. These functions and specification are derived from the actual field studies conducted during the IVAR project: Thus, they represent the operational capabilities of systems that were on the market when that study concluded (2010). Nonetheless, the IVAR staff has endeavored to frame these capabilities in a generic and vendor-neutral form. In doing so, the objective is to use these specifications as a baseline to which additional functions, or better performance of existing functions, can be added from other systems on the market today or from new systems coming on the market. Avian radar systems are a new and rapidly developing technology; consequently, any list of functional requirements and performance specifications will, of necessity, be a dynamic document for the foreseeable future.

Section 2 provides a brief overview of the components that might be included in a typical avian radar system. These components have been subdivided into those that might be included in Standalone, Integrated, or Advanced systems.

The actual functional requirements and performance specifications are presented Section 3, organized into eight subsections. These include the five Performance Objectives categories used in the IVAR Final Report (Brand, 2010) plus radar components, user interface, and operational considerations:

- Radar (Section 3.1)
- Automatic Tracking (Section 3.2)
- Sampling Capabilities (Section 3.3)
- Data Streaming (Section 3.4)
- Data Integration (Section 3.5)
- Data Fusion (Section 3.6)
- User Interface (3.7)
- Operational Considerations (Section 3.8)

Each subsection begins with a brief description of that capability of an avian radar system, followed by one or more functions that fall within that grouping, together with the (usually quantitative) performance specification for each function.

2. Components of an Avian Radar System

The following is an annotated list of components that would typically be included in an avian radar system[1]. They comprise the systems to which the performance specifications that follow would be applied. These components are illustrated in Figure 1 and Figure 2.

We have divided the components of an avian radar system into three groupings: Standalone – components all digital avian radar system would likely include; Integrated – the standalone components, plus those that add functionality to the system for remote viewing and support the combining of information from multiple radars for increased coverage, particularly as it relates to remote access and control; and Advanced – the integrated components, plus those that add analytical functions above and beyond detecting and tracking birds and making the data available to end-users and applications.

It is important to note that the components listed below describe functions an avian radar system should be capable of performing and that these functions may or may not be represented by a separate piece of hardware or software. For example, the hardware and software that make up the radar display processor may be sold as a separate piece of equipment or they may be incorporated into the same chassis as other components, such as the radar sensor transceiver.

Standalone. The following are basic functional components of digital avian radar systems.

> **Transceiver**. The radar includes a *transmitter* that generates the microwave energy radiated to the environment through the antenna, and a *receiver* that processes the electromagnetic energy received by the antenna. Together these components are referred to as the Radar Sensor Transceiver (RST).
>
> **Antenna**. Radiates the electromagnetic waves generated by the transceiver and receives the electromagnetic energy reflected from objects illuminated by the radar beam. The antenna is used to shape or focus the microwaves into a beam of energy transmitted towards and received from a particular direction.
>
> **DC Power Supply.** This component converts standard AC line voltage to direct current (DC) of the proper voltage, which is then used to power the marine radar power supply and the radar display unit. For some RSTs, this component is built into the marine radar power supply unit, which allows the unit to operate directly from alternating current (AC) line voltages.
>
> **Radar Display Unit**. A keyboard (console) used to manually control the operation of the RST, plus a monitor to display the radar returns processed by receiver and display them

[1] See Wikipedia (http://en.wikipedia.org/wiki/Radar) or Radar Basics (http://www.radartutorial.eu/index.en.html) for further information on radar systems.

relative to the position of the radar. Nominally, the radar returns are presented in a plan position indicator (PPI) display.

Radar Digital Processor (RDP). A device that digitizes the radar signals from the RST, then processes the resultant digital data to suppress clutter (see Section 3.2.13), detect and track targets, and record and display the resultant target data (i.e., plots or tracks).

Enclosure. With the exception of the RST and the antenna, all of the components listed above need to be in an enclosed space that protects them from the elements. The enclosure must have electrical power to operate the radar and to heat and cool the space where the components are housed.

Integrated. Includes the components of the Standalone radar configuration plus those used to remotely access, control, integrate, and view the output from one or more standalone radar systems.

Router. A device that links one or more of the radar components to a local- (LAN) or wide-area network (WAN) through a wired or wireless connection, using standard network protocols (e.g., TCP/IP).

Remote Workstation. Digital computer and user software that takes target data from a network data feed or from stored plots and tracks data files and displays them overlaid on a map, satellite image, etc. The software may include other user-configurable functions, such as filters/alerts, basic analyses, and data export utilities.

Remote Controller & Scheduler. A processor that controls the operation and configuration of one or more RSTs and RDPs from either pre-programmed instructions or from instructions entered by an operator on a remote console, or both. May also be used by support personnel to access the system remotely for troubleshooting, software upgrades, configuration, etc.

Data Server. A processor that stores the digital data generated by one or more avian radar systems. Typically a data server would include a digital computer with database management system (DBMS) software configured to receive target data streamed from one or more RDPs and store the data for later playback and analysis. The data server may also be used to redistribute (stream) the data to remote workstations and to store radar processor metadata.

Advanced. Includes the components of the Integrated radar configuration, plus processes for integrating and fusing tracks, and analyzing and summarizing the radar data statistically.

Data Fusion. A process that integrates the target data from two or more radars and/or fuses target data from radars with overlapping coverages into common tracks and presents the integrated/fused tracks in a single display. It can integrate/fuse target data from both “live” real-time data streams and from stored historical data files. Data

integration and fusion are particularly important when more than one avian radar system is deployed at the same facility

Statistical Processing. The process of aggregating and analyzing target data and presenting the information products based on summaries of the data to users in tabular, graphical, or pictorial formats.

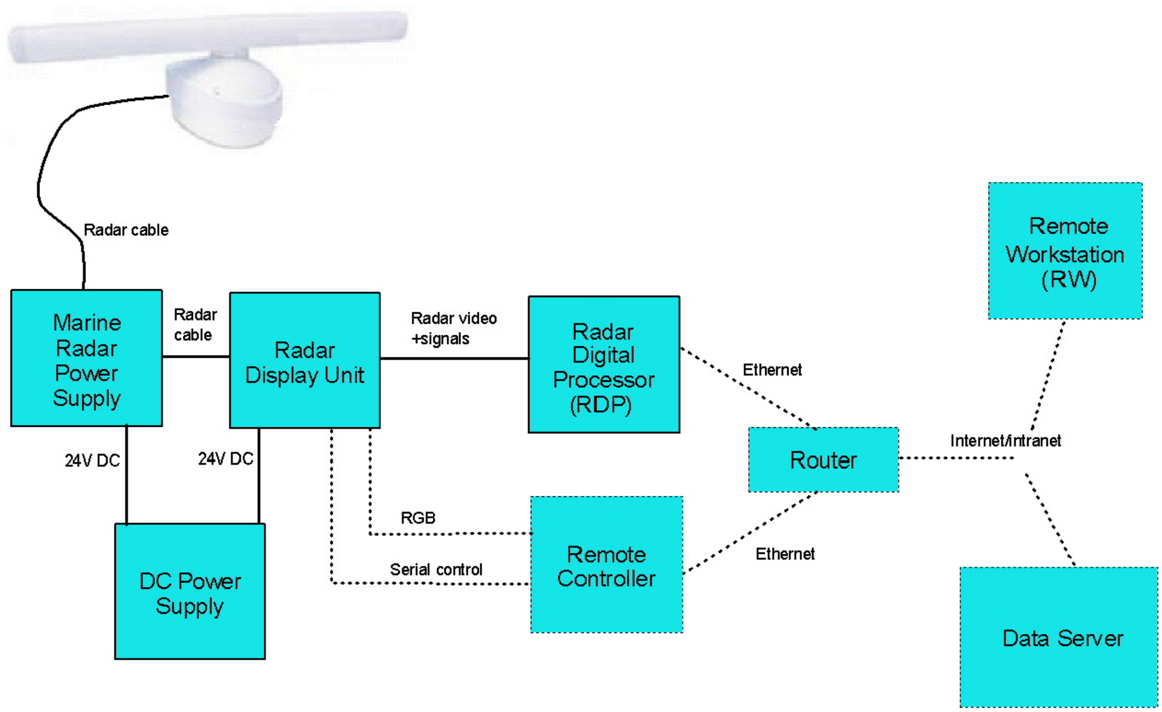

Figure 1. Components of a digital avian radar system.

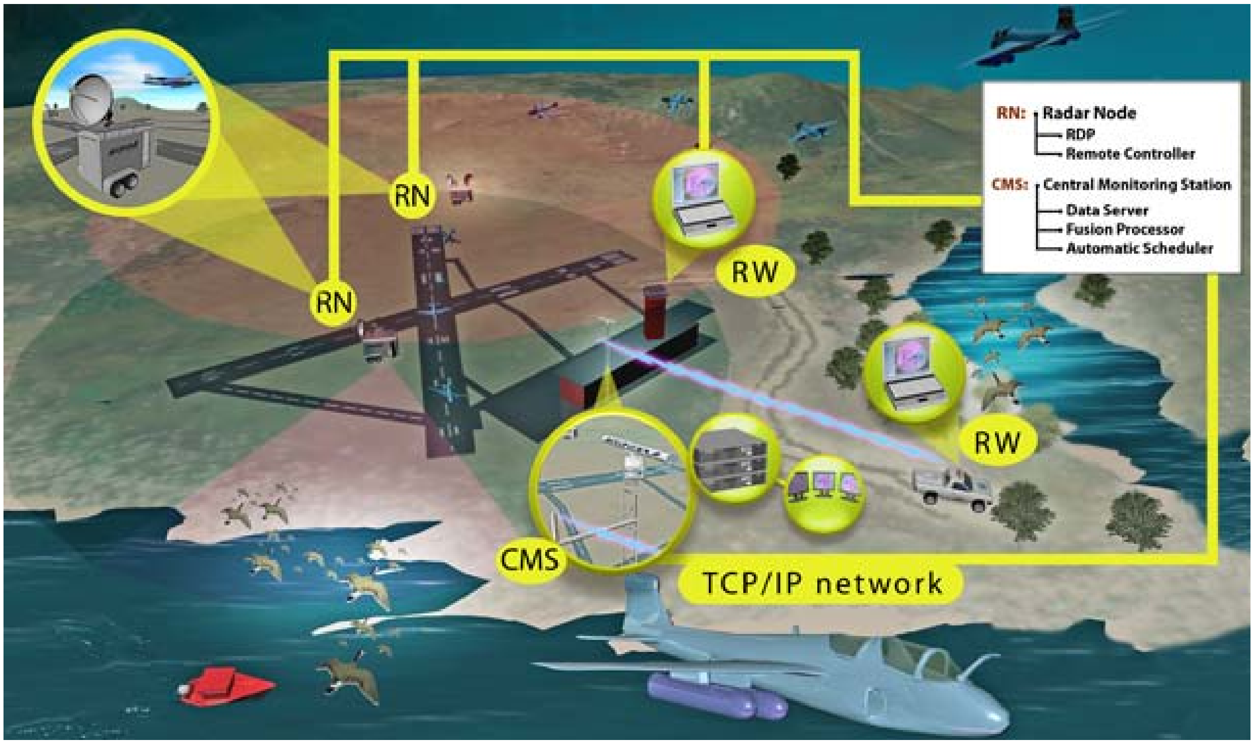

Figure 2. Conceptual diagram of an avian radar network.

3. Functional Requirements and Performance Specifications

A functional requirement is an action or a process a system – in this case an avian radar system - should be capable of performing. It defines what the system should do. A performance specification is a limit to which a system should be able to perform the specified function.

In this section we have divided the performance specifications of avian radar systems into eight categories. Within these categories, each specification includes both a statement of the function the system should be able to perform, followed by the level at which the system should be able to perform that function.

- Radar (Section 3.1) – the capabilities a radar (i.e., RST and antenna) should have in order to detect birds.
- Automatic Detection and Tracking (Section 3.2) – the capabilities the system (i.e., the radar plus the RDP) should have to automatically detect and track birds.
- Sampling Capabilities (Section 3.3) – the capabilities the system should have in order to track birds in the locations, under the conditions, and in the manner required by the user.
- Data Streaming (Section 3.4) – the capabilities needed to transmit the radar data from where they are collected to where they will be used.
- Data Integration (Section 3.5) – combining the detection and track data output by two or more avian radar systems into a single display.
- Data Fusion (Section 3.6) – combining the tracks from two or more avian radars systems with overlapping coverages into common tracks on a single display.
- User Interface (Section 3.7) – how the user interacts with the avian radar systems – how target data are displayed, what features the user can control, etc.
- Operational Considerations (Section 3.8) – features and capabilities that are not functional requirements of an avian radar system *per se*, but which should be considered regarding the operation of avian radar systems.

3.1. Radar

The radar components in an avian radar system must have the signal sensitivity to support detection of a bird of a given size at a given range so that the RDP can automatically detect and track the target through time and space. However, given the variation in the size, shape, and flight dynamics of different species of birds; the different operational settings and end-use applications for avian radars, and the different types of radars that might be employed for this purpose, no single set of specifications for the radar's functional capabilities can be established in advance. Instead, the subsections below outline the general functions and specifications for

radars used in systems designed to track birds. The “best” combination of capabilities will depend upon the planned application(s) for the system.

3.1.1. FCC Approved

Avian radars, like all radars, should be operated in a manner that minimizes interference with other electromagnetic devices.

All makes and models of RSTs operated within the United States must be approved by the Federal Communications Commission (FCC).

3.1.2. Scan Period

The scan period is the time required for the radar to scan the entire coverage volume (see Section 3.3.1). For radars with rotating antennas, the scan period would be equivalent to one complete revolution of the antenna.

The time required for the radar to complete successive scans of the coverage volume should be short enough that the targets will not have moved a significant distance during that period of time. The 2-3 s scan period of most marine radars is sufficient for this purpose (i.e., a bird flying 60 km/h [~40 mph] would travel ~44 m [~144 feet] in 2.5 s).

3.1.1. Power

The average power output of the RST determines in part how much transmitted microwave energy will be available to illuminate a target at a given range.

While average power for avian radar systems is achieved differently depending upon the type of radar transceiver used, it should be at least 5 Watts. For radars that use a magnetron to generate microwaves, this usually translates to a peak power output of at least 25 kW (for “short pulse” waveforms) in order to detect bird-sized targets throughout the coverage volumes discussed below. Solid-state radar transceivers use less peak power output to detect the same bird-size targets, but compensate by using longer pulses.

3.1.2. Range

The radar employed for an avian radar system must have sufficient range to detect birds in the desired coverage volume (e.g., within the perimeter of an airfield or an operational range).

The radar should be preconfigured with the appropriate range setting for the intended coverage range or provide user-selectable range settings (e.g., 1, 2, 5, 10 km).

3.1.3. Frequency

Frequency is a first-order consideration when designing any radar system. For the same size antenna, the higher the frequency (i.e., shorter the wavelength) of the transmitted radar signal the:

- Closer together two targets can be in azimuth while still being resolved as separate targets.
- Greater the effective power, which translates to detecting targets at greater distances.
- More accurate the estimate of target azimuths.

Bird target scattering properties and clutter (e.g., rain) scattering properties are also impacted by frequency, but the trade-offs are complex in nature and depend upon a number of factors that are beyond the scope of this report.

Avian radars systems, including those tested in IVAR, often employ X-band radars that operate in the 8.0-12.0 GHz frequency band (~3 cm wavelength). Other frequencies, notably S-band (2-4 GHz; ~10 cm wavelength) and L-band (1-2 GHz; ~23 cm), however, are being employed in commercial avian radar systems.

3.1.4. Antenna Type

The antenna radiates and shapes the electromagnetic waves generated by the RST; it also receives the electromagnetic energy reflected from objects illuminated by the radar beam.

The RST should permit the use of antenna types appropriate to coverage volume needs and altitude discrimination. Antennas commonly used with marine radars include slotted array and parabolic dish configurations.

The associated RDP should include options that permit the operator to specify the type and size of antenna being used and, in the case of dish antennas, the angle of inclination (up-tilt) so that the computation of track parameters (e.g., target height) can be adjusted accordingly (see also Section 3.8.1).

3.1.5. Sensitivity

The RST must have sufficient sensitivity to detect the received energy from bird-sized targets throughout the coverage volume.

3.1.6. Transceiver Outputs

The function of the radar RST/antenna combination is to illuminate the targets within the coverage volume while the function of the RDP is to detect, track, gather and record data on the moving targets the radar has detected. The RST must, therefore, provide the receiver outputs and timing signals in a form that the RDP can use to perform the functions listed in the sections that follow.

3.2. Automatic Detection and Tracking

Automatic detection and tracking is the process by which the radar system (typically, software in the RDP) detects potential targets from among the received radar signals, determines over the course of several scan periods which detections might be from the same target, associates and

filters those detections into a "confirmed" track for that target, and continues to track the target until it passes out of the radar beam or can no longer be reliably associated with new detections. In essence, these detection and tracking algorithms implemented in software replace what a human would do when observing a radar display and deciding which radar returns are avian targets.

While the detection and tracking software requires the input data to be in digital form, the marine radars used for most avian radar systems currently on the market have analog output. Consequently, the first step in the automatic detection and tracking process for these systems is to digitize the analog waveform data supplied by the RST.

Birds lack the characteristics of the targets the marine radars were designed to detect: birds are small, highly maneuverable in three-dimensional space and small radar reflectors. In addition, the size of adult birds differs from less than 10 cm^2 to about 0.5 m^2 in cross-section, depending upon the species. The RST must therefore be able to receive reflected microwave energy from targets with these characteristics, while the RDP must be able to form tracks from detections that might be only slightly above a threshold that is slightly above background noise for maximum sensitivity.

In order to automatically detect and track birds in their natural environment over a range of operating conditions and to extract and record the pertinent target data, an avian radar system should be able to perform at the specified level of performance for the functions listed in the subsections that follow.

3.2.1. Verification of Automatically Tracked Targets

Automatic tracking involves using computer hardware and software to perform the tasks humans performed when observing the analog radar display before digital signal processing and sophisticated tracking algorithms were available and affordable. That is, the software is now making the determination of which returns are birds, which returns are from the same birds, then forming tracks from the radar returns for the same target, and recording the coordinates of the targets through time. Because the data generated by avian radar systems will be used to make important management decisions, it is critical to have independent verification that the automatic tracking mechanisms are working correctly and accurately.

The vendors of an avian radar system should be able to provide third-party documentation that demonstrates their systems' ability to detect and track various species and sizes of birds, at different ranges, and over a range of environmental conditions, has been verified using independent methods. Brand (2011) provides detailed descriptions of two techniques the IVAR researchers employed to independently verifying that tracked targets are birds (or other biological targets). The first technique involved visual confirmation of targets being tracked by the radar. This method consisted of a single two-person "radar team" (RT) that operated the radar and transmitted (via a two-way radio) information about the location of targets tracked by the radar, plus 3-5 two-person "visual teams" (VTs) positioned at various ranges and bearings

from the radar. One member of each team served as the observer (of the radar for the RT, of the birds for the VTs), while the other person operated the two-way radio and recorded the observations. The teams were deployed during two-hour sessions distributed over a 3-5 day study period at each location. The sessions were staggered to representatively sample morning, mid-day, and afternoon periods of bird activity. These time periods were chosen because of the differences in bird activity and visibility associated with each period. Different species are most active at different times of the day. For example, vultures, raptors, herons, and other soaring species are most common from mid-morning through late afternoon. Other species have peak activity periods in the morning and early evening. Humidity, dust, and other suspended particulate material vary in their influences on visibility through the day and affect the ability of the observers to see and identify birds detected by radar. The dates of the study at each location were chosen to coincide with expected periods of high-density bird activity (local spring and fall migration) at that study location. Four locations were chosen to collect the visual-confirmation data (NAS Patuxent River, MD; MACS Cherry Point, NC; NAS Whidbey Island, WA; and Elmendorf AFB, AK) to evaluate the efficacy of the radar system in a variety of biological and geophysical conditions and radar clutter patterns.

The IVAR project researchers used two protocols for initiating visual confirmation of radar targets. In the first, termed “RT-Calls”, the radar team selected a target being tracked by the radar and transmitted to the visual team closest to that target the range and bearing of the target from the visual team’s position, and a unique identifier for that “request for confirmation”. If that visual team located the target and confirmed that it was a bird, they transmitted confirmation to the radar team. The target’s estimated range, bearing, and angle of elevation from their location, and the taxonomic identification of the target were recorded onto the visual team’s data sheet. The radar team also logged the observation as confirmed or not confirmed. If another visual team also confirmed the same target, they too transmitted their confirmation to the radar team and recorded the data onto their data sheet. Although the radar targets appeared at random around the radar, the radar team attempted to choose targets in all quadrants and at all ranges from the radar to provide a representative sample of the birds detected.

The second protocol, termed “VT-Calls”, was initiated when a visual team observed a bird they thought was within the radar beam and being tracked by the radar. The visual team then transmitted the target’s range and bearing relative to its position to the radar team for the radar team to confirm that the target was being tracked by the radar. If the radar team confirmed that a target fitting the visual team’s description was being tracked by the radar, they transmitted confirmation to the visual team, and both teams recorded the same information about the target as described for the “RT-Calls” above in their logs.

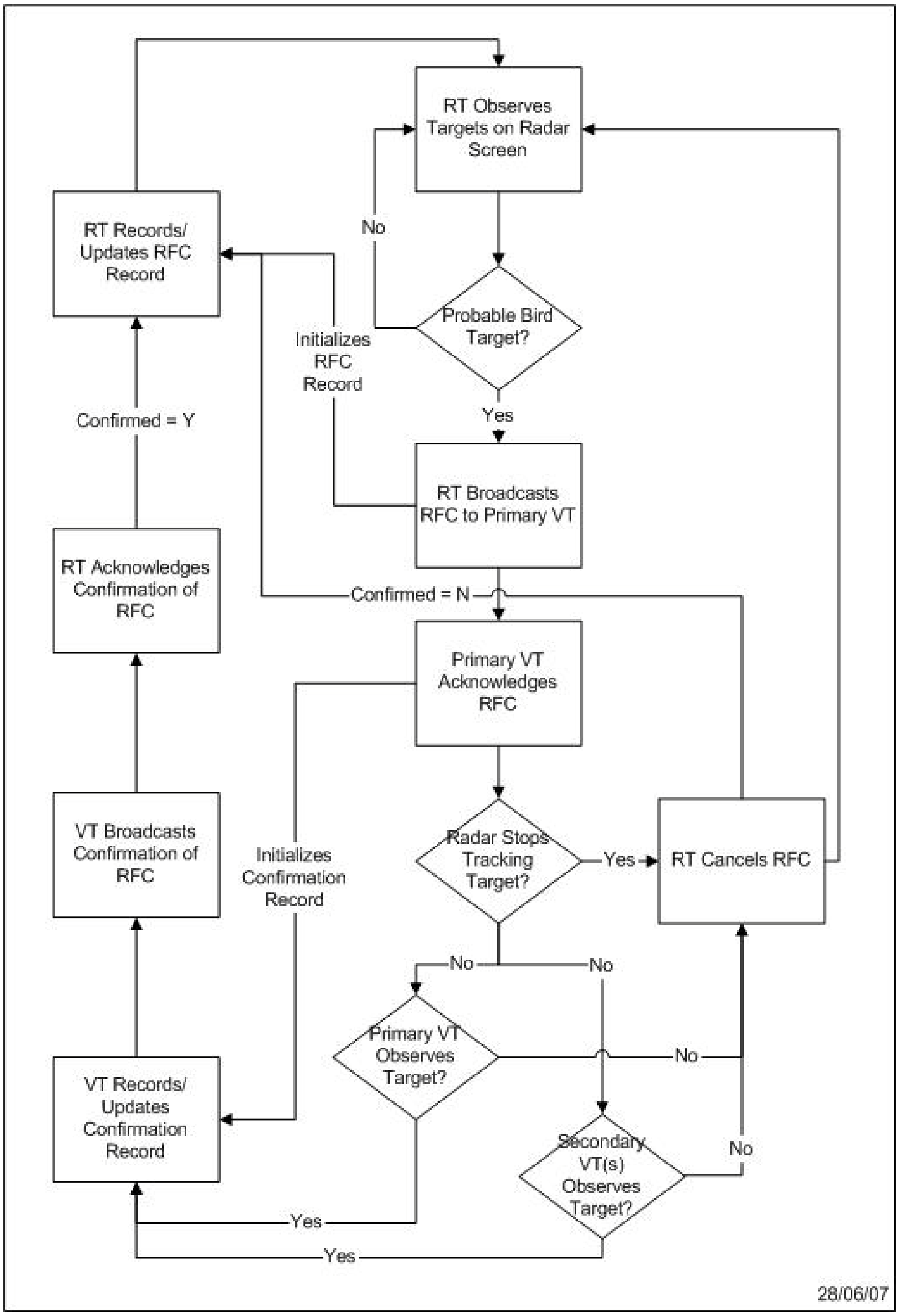

Figure 3. Flowchart of visual target confirmation process employed by the IVAR project. RT=Radar Team, VT=Visual Team, RFC=Request for Confirmation

An observation session could consist of all RT-Calls, all VT-Calls, or could be divided into periods of each type of call, but the RT-Calls and VT-Calls were never intermixed. Figure 3 is a generalized flow diagram of the visual confirmation process employed by the IVAR project. The radar team and the visual teams met after each session to compare their confirmation logs,

resolve inconsistencies and incomplete records, and to categorize each request for confirmation as having confirmed the target, not confirmed the target, that the team did not hear the call, the call was aborted before the attempt to confirm the target could be completed, or “Other”. Only targets that were confirmed or not confirmed were included in all subsequent analyses. Analyses included detection rates of radar and visual observers, the fraction of radar targets that were visually confirmed to be birds, the fraction of visual targets that were detected by the radar, the relationship between distance, target size, and detectability, as well as changes in detectability with time of day and season.

The IVAR project employed thermal observations as the second method to confirm that targets being tracked by the radar were birds. This method was employed at night to observe nocturnal migration when direct visual observations could not be made. These observations were made at a location that was a known range and bearing from the avian radar. The nocturnal observations were made using a vertically-oriented thermal imaging camera and an X-band marine radar with a vertically-oriented dish antenna (Figure 4). The camera was oriented such that north was at the top of the image and west was on the right side of the visual field. The thermal imaging camera detected biological targets by their heat signatures and the direction of travel measured relative to north by the trail of detections across the display. The altitude of each target above the ground was measured by the vertically-oriented radar. The analog outputs from both the thermal imager and the associated radar, together with the date/time, were multiplexed and recorded with a DVD recorder onto writable DVDs. Later these recordings were replayed in the laboratory to extract the longitude, latitude, altitude, speed, and heading of biological targets. The coordinate data for the targets tracked in the coverage volume of the thermal imager were then compared to the coordinate data for the targets tracked by the avian radar through the coverage volume of the thermal imaging camer to identify which of the avian radar targets were birds.

Figure 4. The thermal imager (Radiance I high-resolution thermal imaging camera) on the right and the vertically pointing radar (Furuno FR2155-BB 50 kW X-band radar with a vertically-pointing parabolic dish antenna) employed by the IVAR project to confirm targets tracked by an avian radar at night were birds.

The second technique the IVAR project used to validate the radar track data employed an unmanned aerial vehicle (UAV), specifically a remotely controlled helicopter (Figure 5), with an onboard recording global positioning system (GPS) to verify the 3D coordinates of targets computed by the avian radar system. The UAV was flown along a straight line and moved into and out of the radar's beam. The coordinate data from the GPS were then compared with the coordinates for radar tracks of the UAV to determine how closely the two sets of coordinates matched and how well the radar maintained track continuity as the UAV moved in and out of the radar beam for brief periods of time. This demonstration also illustrated the effects of radar shadowing on target detection and the importance of using tracking parameters specific of individual locations.

Figure 5. Remotely controlled helicopter with onboard recording GPS used to validate spatial coordinates of targets tracked by the avian radar system.

3.2.2. Unattended Operations

Another advantage of automatic tracking is that the avian radar system should be able to operate on its own, without human intervention except for periodic maintenance, reconfiguration, etc.

In order to *automatically* track birds, an avian radar system should be capable of performing the functions listed below on its own, without operator intervention. See also Section 3.2.12.

3.2.3. Track in Four Dimensions

A target's position in time and space are the most critical parameters that can be derived from an avian radar system. The radar itself returns three of the four parameters: Range and azimuth (from which latitude and longitude or other earth coordinates, can be calculated) and time. The target's height above ground level must be calculated but it is critical in many applications of avian radar system technology.

An avian radar system should be able to simultaneously detect and track birds in three spatial dimensions (i.e., azimuth, range, and with an appropriate antenna, altitude), plus date/time, and record these coordinate data in standard earth coordinates (see Section 3.2.9) for each tracked target.

3.2.4. Size of Targets

As noted above, birds are small radar reflectors and highly maneuverable.

An avian radar system should be able to detect and track all sizes of birds (i.e., 10-1200 cm in length, 3-1500 g in mass). The maximum range at which the radar should be able to detect and track birds of various sizes is approximated by the curve shown in Figure 6. As a baseline, an avian radar should be able to detect and track a 1.1 kg (2.5 lb) bird like a duck (RCS ~-16 dBm^2) at a distance of at least 5.6 km (3 nautical miles).

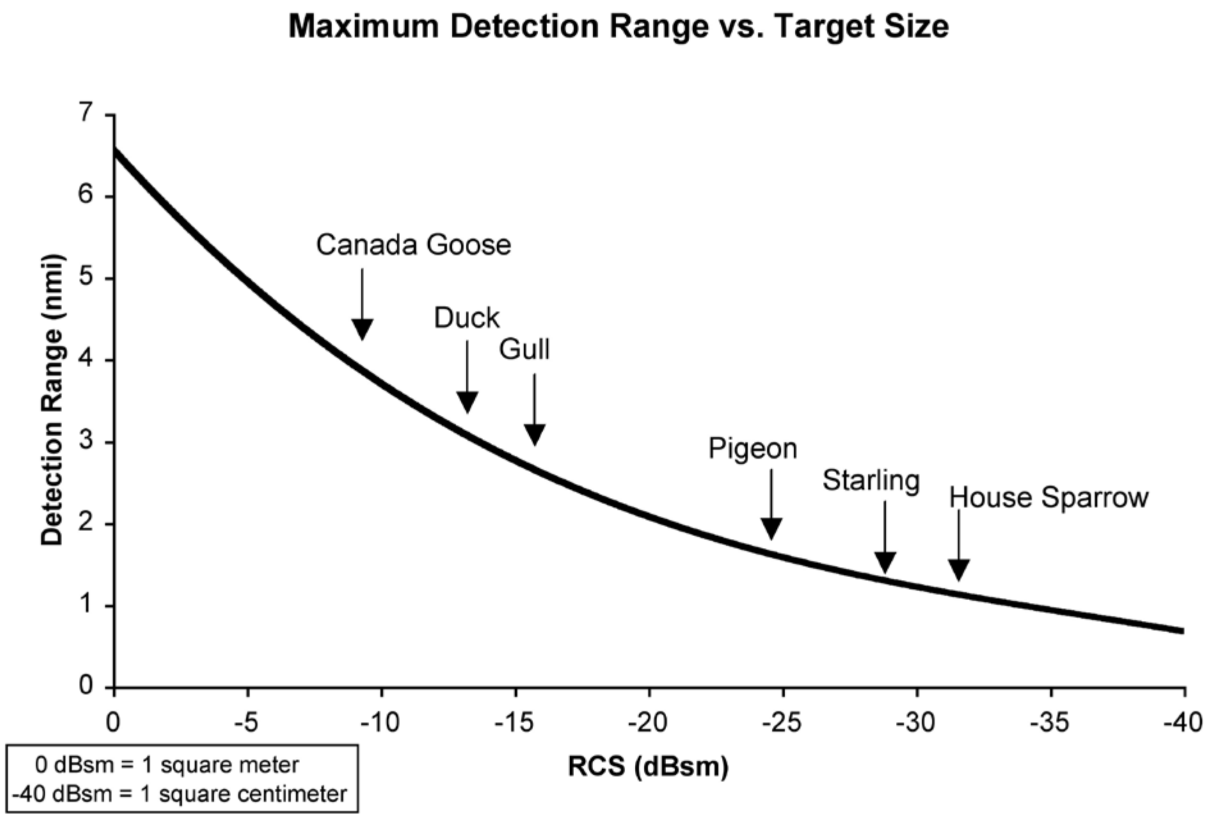

Figure 6. Maximum target range versus the size of the target. These calculations are based on a radar transmitting 10 W average power and an antenna gain of 31 dB. Source: *Avian Radar Performance*. Accipiter Radar Technologies Inc., Fonthill, Ontario, Canada. July, 2008[2].

3.2.5. Real-Time Tracking

Brand (2011) provides an operational definition of the term "real-time" as it relates to avian radar systems[3]. Tracking birds in real-time (i.e., "as it happens") is an important requirement for some applications of avian radar systems.

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[2] RCS = Radar Cross-Section (http://en.wikipedia.org/wiki/Radar_cross-section)

[3] "'[R]eal-time" is used in this and other IVAR documents to mean that the processor can continuously track the movements of all confirmed targets within the sampling volume of the radar beam, including computing and

An avian radar system should be capable of updating and recording the spatial and temporal coordinates, plus related parameters (see Section 3.2.6), for every tracked target during each scan of the radar; for COTS marine radars, this would typically be every 2.5 seconds (see Section 3.1.1).

3.2.6. Forms of Output Data

Microwaves are transmitted and received as analog waveforms. The analog data that are received by the RST must be digitized before they can be processed by the hardware and software that reduce clutter, detect potential targets ("plots") among the radar returns, and associate plots from successive scans of the radar into confirmed "tracks".

Because the primary objective of an avian radar system is to detect and track birds, the specifications for target data presented here focus on the plots and tracks data. This focus notwithstanding, an avian radar system should also provide the option to record the digitized raw radar video in a format (e.g., B-scan video) that permits these data to be reprocessed later to generate new plots and tracks from the same data, perhaps using different configuration parameters.

An avian radar system should record both plots and tracks data for all targets in a form that permits these data to be replayed for display and analysis using vendor or third-party products. The data records should retain the links between each track and the plots used to form that track.

3.2.7. Output Data Format

Once the plots and tracks data have been computed by the RDP, it is important to record them in a format that is readily accessible to humans and computer programs alike.

The avian radar systems should record the plots and tracks data in a format that is user-readable and defined in a data description document ("data dictionary"). This requirement does not stipulate how the plots and tracks data are stored internally, only that the suite of software tools that come with the system can be used to view the data in a consistent user-readable format (e.g., text).

At a minimum, the user should be able to access the parameter values listed under Track Data (Section 3.2.9) and Configuration Data (Section 3.2.11) as text in the American Standard Code for Information Interchange (ASCII) format. Outputting the spatial and temporal coordinate data in an open-source format (e.g., Keyhole Markup Language, KML) compatible with geographic information systems (GIS) and other third-party products is also desirable.

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recording all parametric data for each of the targets, in the time it takes for a single scan of the radar – nominally, 2.5 seconds for the avian radar systems used in the IVAR studies." (Brand, 2010, Section 2.2.1).

3.2.8. Target Identifier

Avian radar systems are capable of tracking hundreds, even thousands, of birds simultaneously. Over the course of months and years, the total number of tracks recorded can become extremely large. It is important, therefore, that these tracks, and the data associated with them, have a globally unique identifier. "Globally unique" in this context means the identifiers generated by one avian radar system would be unique over time and from those generated by all other avian radar systems.

An avian radar system should assign a globally unique identifier (Track ID) to each tracked target that distinguishes that target from all other targets being tracked by that radar, as well as those tracked by all other avian radars. The Track ID should also associate a target with all data generated and recorded for that target.

Track IDs, when displayed on a computer monitor, should be short enough to avoid a muddle of overlapping labels in areas of high target density, but long enough (or linked to a longer label) to make them globally unique.

3.2.9. Track Data

The goal of tracking targets with avian radar systems is to gather data about the targets that can be used in applications ranging from natural resources management to bird-strike avoidance.

During every scan an avian radar system should capture and record on a mass storage medium (see Section 0) the plots and tracks data of each tracked target. The plots should be linked to the tracks they were used to create and the track data should include the unique target identifier for each track, as well as the associated parametric data listed in Table 1. Section 3.2.7 provides a discussion of user-readable formats for these data.

Table 1. Parameters recorded for each tracked target during each scan of the radar. *Italicized parameters* are optional.

Parameter	Units	Datum	Precision	Comments
Track ID				Globally unique identifier of each tracked target
Longitude	Decimal Degrees	WGS84[4]	10 m	
Latitude	Decimal Degrees	WGS84[4]	10 m	
Altitude	Meters	AGL[5]	1 m	

[4] World Geodetic System, 1984 (http://en.wikipedia.org/wiki/WGS84). By convention, values is the southern and western hemispheres are recorded as negative values (e.g., -122.6668056 = 122.6668056 west longitude).

[5] Above Ground Level (AGL). This parameter assumes the height of the radar antenna above the ground surface has been included in the computation of the target's altitude AGL (see "Antenna and Scanner" in Section 3.8.1). This

Parameter	Units	Datum	Precision	Comments
Date		UTC[6]	1 d	20080624 = June 24, 2008.
Time	24-hour clock	UTC	0.1 s	00:00:00.0 = Midnight
Heading	Degrees	True North	1°	
Speed	m/s		1 m/s	
Range	Meters		1 m	
Azimuth	Degrees	True North	1°	
Intensity	Relative			"Brightness" of a received signal relative.
Spatial Covariance				Uncertainty in target's spatial coordinates.

3.2.10. Track Capacity

The number of birds in the coverage volume can range up to thousands of individuals. Experience has shown that it is not uncommon for an avian radar system to track several hundred targets simultaneously during periods of peak bird activity such as migration.

At a minimum, an avian radar system should be capable of continuously and simultaneously detecting, tracking, and recording data for at least 100 moving targets. The actual number of targets a system is capable of tracking simultaneously may be higher, depending upon the performance of the hardware and software components implemented in the RDP.

3.2.11. Configuration Data

Assessing the quality and interpreting the results of parametric data that are recorded for tracked targets will depend upon knowing the configuration of the radar and processor when the data were collected.

In addition to data about the characteristics of the tracked targets, an avian radar system should also maintain a record of the state of the system while the tracking data were being collected. While the specific nature of these "configuration data" (part of the larger category of "metadata") will vary from system to system, typical configuration parameters are listed in Section 3.8.1.

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parameter further assumes that the position of the radar antenna and the target's ground track position (http://en.wikipedia.org/wiki/Ground_track) are in the same horizontal plane - that is, there has been no correction for topography (relief).

[6]UTC = Universal Coordinated Time (http://en.wikipedia.org/wiki/Utc); approximates Greenwich Mean Time (GMT).

3.2.12. Programmed/Remote Control

As noted in Section 3.2.2, an avian radar system should be capable of being operated unattended.

"Unattended" in this context may include the following modes of operation:

- Set and Forget. The operator powers up the radar systems, starts it running and recording, and leaves it operating continuously.
- Programmed. The operator creates a set of instructions (i.e., a program) that specifies the date and time when the system should power-up, the configuration parameters under which the system should operate, when it should start transmitting and recording, when it should stop transmitting and recording, and whether it should shut down completely or remain in standby until the next programmed event occurs. Once invoked, this program controls the operation of the avian radar system.
- Remote Control. While not strictly unattended operation, remote control permits the operator to remotely control, via a network connection, the operation and configuration of the radar system. Remote control should also include the ability to change the control program (see "Programmed" above).

For each of these modes of operation, the operator should have the ability to control the following functions:

Radar transceiver (RST):

- Power On/Off
- Transmit/Standby
- Waveform Selection (e.g., Short, Medium, or Long Pulse)

Radar digital processor:

- Power On/Off
- Start/Stop the digitizer
- Select configuration file to use

3.2.13. Dynamic Clutter Management

"Clutter" refers to radar returns from objects that are not of interest to the radar operator. Clutter can affect radar performance both by masking the movements of small targets (e.g., birds) moving above the clutter and by overwhelming the tracking algorithms with "false detections." In order to reliably detect and track birds, the RDP must suppress clutter to a manageable level without also removing the targets it is attempting to track, and it should do so dynamically by adapting to temporal and spatial changes in the clutter environment.

Avian radar systems are typically positioned near the ground with a low (close to horizontal) antenna angle. Thus, two of the common sources of clutter are "ground clutter" (i.e., radar returns from the land surface, buildings, trees, and other stationary objects), and "sea clutter" (i.e., radar returns from surface waves and "wind chop" on open bodies of water). Other sources

of clutter include precipitation, dust, and atmospheric disturbances. Bats, insects, other biological targets, and vehicles (e.g., planes, cars, and boats) also fit the definition of clutter if they are not of interest to the operator, although they are typically differentiated from the avian targets by mechanisms other than clutter suppression.

Avian radar systems should adapt automatically and dynamically to changing clutter conditions and maintain a constant false alarm rate (CFAR). Algorithms for ensuring CFAR typically estimate the clutter levels in each radar resolution cell, and then set detection thresholds accordingly. The level estimates are based on temporal variations and/or statistics, with two common techniques being clutter map processing and CFAR processing.

The RDP should also suppress "noise", whether from internal variations in the signal generated by the electronic components or from an external source such as a nearby radar operating in the same band.

3.3. Sampling Capabilities

Sampling capabilities encompass those functions an avian radar system needs to perform in order to sample birds in their natural environment, under typical operating conditions, in accordance with the operator's requirement.

3.3.1. Coverage Volume

The coverage volume is the three-dimensional space within which an avian radar system is able to detect and track birds. The effective dimensions of the coverage volume are dependent upon several factors, including the size, shape and orientation of the antenna, as well as the instrumented range of the transceiver and RDP. The average transceiver power, the target resolution capabilities of the radar, and the sophistication of the RDP's detection, tracking, clutter-suppression, and other algorithms influence the maximum range at which a particular size of bird can be reliably detected and tracked within the coverage volume. Clearly, larger birds will be detected and tracked at greater distances from the radar transceiver (i.e., its distance from the center of the coverage volume) – see Section 3.2.4.

At a minimum, an avian radar system should, during each scan of the radar, be able to detect and track birds:

- Through 360° of azimuth from the radar (i.e., "field of view")
- For large birds and flocks (e.g., raptors), at a range of at least 11 km from the radar
- At altitudes from near ground level up to 1 km or more above ground level (AGL)

3.3.2. Period of Operation

The period of operation is the amount of time the avian radar system can be continuously transmitting, detecting and tracking targets, and recording the data derived from the tracked targets.

Because birds can be active at any time, an avian radar system should be capable of operating unattended continuously, 24 hours per day, 7 day a week, and 365 days a year.

3.3.3. Masking, Filtering, and Alerting

Masking, filtering, and alerting describe actions an avian radar system might be configured to take based on the characteristics of targets that are being tracked within the coverage volume. These capabilities may be used to suppress the display of extraneous information, emphasize the display of selected information, or notify personnel or other software systems of target activity that may require further action. Examples of these capabilities include:

- Suppress tracks in areas where returns from man-made structures such as buildings or construction vehicles may obscure targets of interest or distract an operator (i.e., a mask).
- Suppress the tracking of aircraft based on a user-specified threshold for maximum target speed (e.g., a filter).
- Sending a text message to wildlife personnel when a specified number of birds have entered a restricted space (i.e., an alert).

While the implementation of these capabilities will vary between vendors, the avian radar system should permit the user to specify:

- The boundaries[7] of one or more “action spaces” within the coverage volume.
- Complex regions with overlapping action spaces within the coverage volume
- Test conditions for target characteristics within an action space.
- The action(s) that should be triggered when a target meets the test conditions within an action space.
- Selectively turning actions “on” and “off”.

The avian radar system should also enable the user to set the test conditions within an action space by setting thresholds for conditions such as the targets’:

- Speed
- Heading
- Altitude
- Abundance (number of targets)
- Duration (time targets in action space)

Finally, the avian radar system should enable the user to specify the action that is triggered when the test condition threshold is met within an action space, such as:

- Suppress the display of targets meeting a specified threshold
- Generate an audible alarm

[7] Two- or three-dimensional, based on the radar system configuration.

- Highlight an area on the display monitor
- Send an email or text message that describes why the alert was generated
- Set off pyrotechnics to scare away birds approaching a restricted area

3.3.4. Data Storage

Data storage refers to the amount of mass storage, in the form of a hard disk or other digital medium that is required to store the data generated by an avian radar system. The focus here is not on the storage medium *per se*, but rather on the efficiency with which avian radar system generates the data that need to be stored. If the amount of data generated is too voluminous, storing the data from the continuous operation of the radar could become cost-prohibitive.

The amount of data generated by an avian radar per unit time depends on many factors: The data storage format, the number of targets being tracked, the number of parameters recorded for each update of each target, etc. As a general guideline, it should be possible to store the plots and tracks data, plus associated metadata (see Section 3.2.11), for all targets tracked by a single radar operated continuously for one year on a commercial off-the-shelf (COTS) storage medium with a capacity of 1 TB (10^{12} bytes) or less. See also Section 3.4.10 for a discussion of data servers.

3.4. Data Streaming

Data streaming is the process of transmitting the data generated by the RDP from where the data were collected to where they will be displayed, analyzed, or stored. Data streaming may be *internal* (e.g., between the computer processor and an internal hard drive), *local-area* (e.g., within a facility), or *wide-area* (e.g., between facilities perhaps separated by thousands of kilometers). These local- and wide-area transfers utilize computer networks. These same network connections may be employed to support other functions, such as remote control, troubleshooting, and software upgrades.

The specifications presented in this section assume data are being streamed in real-time[3] because real-time data streaming typically requires higher sustained data transfer rates than intermittent transfers that simply store the data for later analysis and display.

3.4.1. Bandwidth

Bandwidth is a measure (usually expressed in Mbit/s) of the average rate of successful message delivery over a communication network.

The amount of bandwidth required for an avian radar system will depend on many factors, including the distance over which the transfer occurs, loading on the network from other applications, and the output data rate of the radar processor. In general:

- Data streaming between computer components (e.g., between the RAM memory and a hard drive) using a bus architecture[8] will provide the highest bandwidth
- At present, streaming raw digitized B-scan video (see Section 3.2.6) is only feasible over a computer bus or a dedicated high-speed (e.g., CAT5[9], fiber optic, dedicated microwave point-to-point) network.
- Wired connections (e.g., both cable and fiber optic) provide faster and more reliable throughput of plots and tracks data than wireless connections
- Among wireless connections, dedicated wireless fidelity (WiFi) links can usually support real-time streaming of plots and tracks data from avian radar systems, while third-generation (3G) cellular data links may be too slow for this purpose if the service is unreliable or variable.

3.4.2. Network-Capable

Network-capable means the RDP and related components are shipped with hardware and software implementations of standard network protocols that permit these systems to be connected to an existing computer network.

The components that generate and transmit the data (e.g., the RDP) and those that receive and process the data (e.g., the data server) should be network-capable; that is, they should be designed to send and receive data using standard network protocols such as TCP/IP across both local area networks (LANs[10]) and wide-area networks (WANs[11]).

3.4.3. Internal Data Streaming

Internal data streaming refers to the transfer of data between computer components (e.g., RAM[12] memory and a hard drive) using a computer bus architecture.

An avian radar system should be able to stream plots and tracks data to a mass storage device (e.g., hard disk) connected directly to the RDP. It should also be capable of streaming the digital baseband video generated by the radar processor to a mass storage device (e.g., hard disk) connected directly to the processor.

[8] http://en.wikipedia.org/wiki/Computer_bus

[9] http://en.wikipedia.org/wiki/Category_5_cable

[10] http://en.wikipedia.org/wiki/Local_area_network

[11] http://en.wikipedia.org/wiki/Wide_area_network

[12] http://en.wikipedia.org/wiki/Random_access_memory

3.4.4. Network Data Streaming

Network data streaming refers to transferring the data from the RDP to another system (e.g., data server) over either a LAN (e.g., within the enclosure or to another building within a facility) or a WAN (e.g., over the Internet).

An avian radar system should be able to stream plots and tracks data in real-time over wired or wireless LANs or a WAN such as the Internet, using standard protocols such as TCP/IP.

Secure data transmission across networks should also be supported (see Section 3.4.8).

Other types of data (e.g., alerts [Section 3.3.3] and automated controls [Section 3.2.12]) should be supported by these same network protocols.

Transmission of these data should be throttled automatically based on bandwidth (Section 3.4.1) and network availability (Section 3.4.8).

3.4.5. Concurrent Data Streaming

Concurrent data streaming is the ability to stream data, usually the same data, from one processor to two (or more) destinations at the same time.

An avian radar system should be able to concurrently stream the same plots and tracks data from the RDP over a network (see Section 3.4.4) to a remote device (e.g., a data fusion processor) and at the same time to an internal hard drive (see Section 3.4.3).

3.4.6. Near Real-Time Data Streaming

Near real-time data streaming is the ability to stream data from the source (e.g., a RDP) to the destination (e.g., a data server) without introducing significant time delays ("latency").

An avian radar system should be able to stream plots and tracks data across a LAN or WAN (Section 3.4.4) with a latency of 5 seconds or less. Latency in this instance is defined as the difference between the time the plots and tracks data were generated by the RDP and the time they were displayed on a remote workstation or written to a remote database.

3.4.7. Data Integrity

Data integrity refers to the transmitted data arriving at the destination with few if any errors in the transmitted values.

An avian radar system should be able to continuously transmit plots and tracks data across a WAN (e.g., the Internet) without errors other than missing transmissions due to network congestion. An "error" is here defined to be a received datum (e.g., a longitude coordinate) that is different from the transmitted datum.

3.4.8. Data Security

Data security means protecting data from unauthorized access. Data security can take many forms, including: encrypting the data as they are transmitted over a network; physical security to prevent unauthorized access to the RDP or data repository hardware and software; database security, to prevent the retrieval of sensitive data from a data repository by unauthorized personnel or programs.

Because target data from avian radar systems may include information about "sensitive" targets (e.g., the takeoff and landings of military aircraft), and because these data may be transmitted over public networks such as the Internet, it is important that an avian radar system provide a mechanism to prevent unauthorized access to the data as they are being transmitted from the source to the destination. Virtual private network (VPN[13]) software is often used for this purpose. Another mechanism is to filter out sensitive targets before sending the data over public networks.

3.4.9. Network Availability

Network availability is the percentage of a given period of time that a network is operational and transmitting data. While network availability is a function of the network and not the avian radar system *per se*, it is an important consideration when streaming data to a remote site, particularly when streaming the data in real-time.

An avian radar system should be able to continuously transmit plots and tracks data over a wired or wireless LAN and/or a wired WAN with an end-to-end availability (i.e., "up-time") of 90% or higher during a 24 hour period. A network is defined as being "available" if a record transmitted by the processor is received without errors at the other end in near real-time (see Section 3.4.7).

3.4.10. Data Server

A data server is a repository for storing data, plus associated metadata, generated by an avian radar system. The nature of the data stored on the server can range from "raw" data (e.g., B-scan video), to "processed" data (e.g., plots and tracks), to "summaries" of data (e.g., frequency plots of tracks per hour) – the latter category being more properly termed "information" than "data". A server may also be used to store other forms of field measurement data related to avian radar systems, such visual observations of targets that were being tracked by the radar.

In general, a data server includes a computer, operating system, storage media, and associated software designed to store (and retrieve) data for client applications; that is, for one or more avian radar systems. Data servers are generally linked to their client applications via a local- or wide-area network (see Section 3.4.2).

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[13] http://en.wikipedia.org/wiki/Vpn

Data servers are generally of two types: file servers, on which the stored data are organized into "flat files", and database servers, on which the data are stored, managed, and accessed using specialized software known as a database management system (DBMS[14]). In practice, different data may be stored in files and in a database on the same physical server. In addition, the server function may be distributed across separate systems that are networked together.

If DBMS software is employed for storing and managing the target data, the data server should:

- Continuously receive plots and tracks data transmitted in real-time (see Section 3.4.6) from one or more avian radar system(s), over a network, and simultaneously load the records from these source radar systems into prescribed database tables.
- Simultaneously redistribute in real-time the target data from one or more of the source radar systems across a network to remote workstations.
- Provide access to both current (real-time) and historical data.
- Store several years' worth of data from source avian radar systems.
- Be accessed through standard, open-source software interfaces (e.g., SQL[15], XML[16]). These interfaces may employ client-server[17], web services[18] or other standard protocols.
- Access to the database, and to selected data within the database, should be controlled through user accounts (i.e., username/password) or similar security mechanisms.
- Employ a database schema that exhibits "data independence"[19]: That is, the user (human or software) should view the data as being organized into tables and relationships, without requiring knowledge of the underlying physical storage structure of the data.
- Follow industry best-practices for the DBMS being used.
- Access target data from the data server based on a variety of search criteria, such as date/time, location, radar ID, target (track) ID, etc.
- Limit access to "sensitive" data (see Section 3.4.8) based on user accounts or other criteria.
- Export, or otherwise share, data stored on the data server without requiring the use of proprietary software.

[14] http://en.wikipedia.org/wiki/Dbms

[15] http://en.wikipedia.org/wiki/Sql

[16] http://en.wikipedia.org/wiki/Xml

[17] http://en.wikipedia.org/wiki/Client-server

[18] http://en.wikipedia.org/wiki/Web_services

[19] http://en.wikipedia.org/wiki/Data_independence

- Permit others to develop new software products to exploit data in the data server using, for example, the published database schema and standard interface protocols.

3.5. Data Integration

Data integration is the process of combining the plots and tracks data generated by two or more radars into a single display (often referred to as a "Common Operational Picture", or COP[20]). While the radars supplying the data may have overlapping coverages, the integration process makes no attempt to fuse the tracks from the separate radars: It merely displays them in a COP. Data integration is a particularly important function if two or more radars are required to increase coverage of a facility.

3.5.1. Common Operational Picture

A common operational picture, or COP, refers to the display of operational data from multiple sources in a single, integrated display.

The processor that generates the COP for an avian radar system should be capable of accepting the target data streamed from two or more radars that are closely (<1 km) or widely (>100 km) separated and present the target information from these sources in a single display that maintains the correct spatial and temporal registration of the targets.

The integrated target track data are typically overlain on a satellite image or facility map of the study area.

The COP should also identify, through the use of different colors, symbols, or other methods, the source of the target plots or tracks being displayed.

Data from other sensors – video, auditory, etc. – may also be integrated into a COP if they include the appropriate spatial and temporal coordinate data.

3.5.2. Temporal Alignment

Temporal alignment refers to the mechanisms used to keep the system clocks of the RDPs that are supplying the target data to the integration processor closely synchronized.

The time latency of the two (or more) avian radar systems supplying target data to the data integration processor should not exceed 10 seconds. "Latency" in the context of data integration is defined as the difference between the timestamps of the data feeds from the two (or more) radars when displayed side-by-side on a remote, integrated workstation.

3.6. Data Fusion

Data fusion is the process of joining the tracks for the same target from two or more radars with overlapping coverages and replacing the separate tracks with common tracks in a COP. Targets

[20] http://en.wikipedia.org/wiki/Common_operational_picture

that occur exclusively in the coverage of one radar but not in that of the other(s) are displayed in the COP as integrated targets (see Section 3.5). Since the radars supplying the target information are likely to be asynchronous, data fusion requires the capabilities listed in this section in addition to those listed for data integration.

Like data integration, data fusion is typically performed by a separate data fusion processor to which data are streamed from the avian radar systems (or other sensors).

3.6.1. Spatial Alignment

Spatial alignment refers to the mechanisms used to ensure that the radars supplying the target data are properly aligned with respect to standard spatial datums[21]. Since the spatial coordinates returned by the radars typically used in these applications are range and azimuth, proper spatial alignment will in most cases require knowing the accurate spatial coordinates (e.g., latitude and longitude) of the radar antenna and that the radar has been accurately aligned so that 0° of azimuth = true north.

The avian radar systems supplying target data to the fusion processor should maintain a spatial misalignment error for each pair of radar tracks that is less than three times the *a priori spatial uncertainty*. Method #6 in Brand (2011) defines the calculation of the a priori spatial uncertainty.

3.6.2. Temporal Alignment

Fusing target data from two or more independent radars with overlapping coverage requires, as it did for data integration, close temporal alignment of the radars (see Section 3.5.2). The misalignment in the temporal dimension between the avian radar systems supplying the track data must be relatively small in order to successfully associate the separate tracks with the same target.

The time sources for the RDPs should employ standard time protocols, such as the Network Time Protocol (NTP[22]).

The difference between the time sources of the two (or more) RDPs supplying target data to the fusion processor should be less than 5 seconds over the period of one week.

3.6.3. Track Continuity

Track continuity is the result of the fusion processor following the same target as it moves from an area of coverage of one radar, into an area of overlap of two (or more) radars, and then into another area of coverage.

In order to maintain track continuity, the fusion processor should:

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[21] http://en.wikipedia.org/wiki/Datum_%28geodesy%29

[22] http://en.wikipedia.org/wiki/Network_Time_Protocol

- Remove duplicate tracks.
- Join broken tracks.
- Assign a globally-unique ID (see Section 3.2.8), or assign the ID of the "first" track to all tracks contributing to the fused track, to the fused track.

3.6.4. Real-Time Processing

For those applications that require real-time tracking of birds, the fusion process should not add significant delays to the display and analysis of the fused track data.

The fusion processor should carry out the fusion process and display the fused and the non-fused (integrated) tracks in the COP in the same (or less) time that it takes the radars to track the targets (i.e., in real-time).

3.7. User Interface

User interface (UI) is a collective term given to those elements through which the user interacts with the avian radar system. While the specific features and "look & feel" of the interface will be vendor- and in some cases model-specific, generally they will employ graphical icons and visual indicators to create what is referred to as a graphical user interface (GUI[23]).

The features of the UI of an avian radar system listed below describe general functions that should be at the user's control, rather than specific ways of implementing those functions.

3.7.1. PPI Display

As discussed in Section 2, the radar display unit of most marine (and many other) radars visualize the radar returns in what is called a Plan Position Indicator (PPI[24]) format.

Because the PPI display format is so widely used and familiar to radar operators, the RDP of an avian radar system should provide the operator with the option to generate a PPI when displaying target plots and track data to the user. Unlike the PPIs of analog radars, avian radar PPIs are digitally rendered and scan-converted to a Cartesian or raster format suitable for display on standard computer monitors.

A PPI display also permits the operator to compare, side-by-side, the digital display generated by the RDP with that analog display generated for radar display unit supplied with the RST (if available). This comparison, particularly with clutter suppression turned off on the RDP, can be a good test of whether the RDP is faithfully reproducing digitally what the radar system is seeing and displaying in analog form.

[23] http://en.wikipedia.org/wiki/GUI

[24] http://en.wikipedia.org/wiki/Plan_Position_Indicator

3.7.2. Display Range

The operator should have the option to select the maximum range displayed on the monitor; that is, to "zoom in" (smaller maximum range displayed) or "zoom out" (larger maximum range displayed).

3.7.3. Display Plots and Tracks

Plots are detections that have been identified by the RDP from the radar returns; they may or may not be associated with other plots to form a track for a single target. The operator should have the option to display plots, tracks, or both.

The operator should also have the ability to select the display color for both plots and tracks.

3.7.4. Selecting Maps

The operator should have the ability to choose the georeferenced map or aerial photograph over which the target plots and/or tracks data are displayed, and should be able to insert a new georeferenced map or aerial photograph of his or her choosing.

3.7.5. Target Labels

The operator should have the option to turn the labels that identify the currently tracked targets "on" and "off, and to select which target parameters are displayed as the track label. Typical track labels that might be displayed could include one of: Track ID, speed, heading, or altitude.

3.7.6. Track History

A "track history" is a visual display of the prior positions of a target.

The operator should have the option to specify whether or not a track history is displayed for the tracked targets, as well as the duration of the displayed histories. A duration of "1" displays only the current position of the target and is equivalent to turning the track history option "off". A duration of "20" displays the current position of a target, plus the position of that target during the 19 prior scans of the radar.

A track history typically appears on the display as a symbol ("head") that indicates of the target's current position, plus, optionally, a target label (see Section 3.7.4), followed by a "tail" representing the target's prior positions, up to the maximum specified duration.

3.7.7. Linear Units of Measure

The operator should have the option to display linear target data (e.g., range, altitude, speed; see Section 3.2.9) in either metric or US Customary (i.e., "English") units of measure; for example, the operator might want to switch the range marks on the PPI display from kilometers to nautical miles.

3.7.8. Clutter Suppression

The operator should have the option to turn clutter suppression mechanism “on” or “off”.

3.7.9. Playback Speed

When playing back previously recorded data, the operator should be able to control the playback speed on a selectable scale from slower-than-real-time (slow-motion) to faster-than-real-time (time-lapse).

3.8. Operational Considerations

The following issues are not functional requirements of avian radar systems per se; rather, they are factors that should be considered regarding the operation of these systems.

3.8.1. Configuration Parameters

The following is a list of typical parameters describing the configuration of an avian radar system. These parameters, and others necessary to define the operating state of the avian radar, should be recorded in a human-readable file format and associated with and stored with the plots and tracks data generated by the radar processor operating under these configuration parameters.

- Radar transceiver
    - Manufacturer
    - Model number
    - Serial number
    - Avian radar vendor’s identification number
- Antenna and scanner
    - Manufacturer
    - Avian radar vendor’s identification number
    - Type (e.g., dish, array)
    - Dimensions
    - Beamwidth
    - Angle of elevation from horizontal
    - Rotation rate
    - Latitude, longitude, and height above ground level
- Radar waveform parameters
    - Peak power
    - Pulse length
    - Pulse repetition frequency
- Radar Digital Processor (RDP)
    - Avian radar vendor’s identification number

- Software version number
- System time source

- Digitizing parameters
  - Sampling rate and number of bits per sample
  - Maximum range
  - Lines per scan
  - Configuration filenames

- Detection processing parameters
  - Detection algorithms and related parameters (e.g., thresholds, clutter suppression parameters, scan-to-scan integration parameters, etc.)
  - Configuration filename(s)
- Track processing parameters
  - Tracking algorithms and related parameters (e.g., speed and acceleration limits,
  - Configuration filename(s)

3.8.2. Interference

The operation of an avian radar system may interfere with other electromagnetic devices, including other radars, in the vicinity. Conversely, the operation of these other devices may interfere with the avian radar.

As noted in Section 3.1.1, radars operated in the United States must be approved by the FCC.

Avian radar systems deployed at military facilities may further require approval by the spectrum manager at that facility to ensure the radio frequency (RF) emissions from the radar will not interfere with any other electromagnetic or electro-optical equipment.

3.8.1. Safety

The position of an avian radar system at military facilities must be certified that it will not present a Hazard of Electromagnetic Radiation to Personnel (HERP), Hazard of Electromagnetic Radiation to Fuels (HERF), or Hazard of Electromagnetic Radiation to Ordnance (HERO). See for example:

http://www.safetycenter.navy.mil/acquisition/RFR/index.asp

3.8.1. Information Assurance Certification

Before a digital avian radar system can be connected to a US Department of Defense communications network (i.e., any network in the .MIL domain), the entire system - hardware, software, and communications components - must certified under the DoD Information

Assurance Certification and Accreditation Process (DIACAP[25]). The entire system must be recertified when new components are added, and all systems must be recertified every three years.

3.8.2. Reliability and Maintainability

The following are questions vendors should be able to answer related to how reliable the system is likely to be and how easy it is to maintain should something fail.

- What is the mean time between failure (MTBF) of the various components of the avian radar system?
- Is it possible to monitor the "health" of the components of the system (e.g., the magnetron) to determine how close they are to failure?
- Are spare parts readily available?
- Is the software maintainable?
  - Was it written for a widely used operating system (Linux, Microsoft Windows) and in a "modern" programming language (e.g., Java, C++)?
  - Are the software development teams still employed by the vendor?
  - Is the source code still available to the current software development teams?
  - Is there a mechanism in place for reporting and tracking software "bugs"?
  - What is the vendor's policy regarding software upgrades?
- What is the effective lifespan of the system – the time beyond which repairing or replacing components becomes problematic or avian radar technology will have advanced so much that replacing the entire system would be more cost-effective than upgrading individual components?
- How mature is the system?
  - Are the hardware and software components considered commercial off-the-shelf (COTS)?
  - Have there been a significant number of sales and operating hours for the product to judge system maturity (and reliability)?
  - Is the vendor willing to provide a list of customers who have used their products and allow you to choose which customers to contact about their experiences with these products?
  - Has there been any independent verification of the system's performance?
- Refer to the Cost Analysis section in Brand (2011) for a discussion of the costs associated with maintenance and support of avian radar systems.

[25] http://www.dtic.mil/whs/directives/corres/pdf/851001p.pdf

3.8.3. Accessories

3.8.3.1. GPS

A global positioning system (GPS) receiver that continuously supplies the current earth coordinates of the radar antenna to the RDP can be a useful accessory, particularly for mobile avian radar systems. The RDP should, however, also provide a mechanism to enter the antenna's coordinates manually.

3.8.4. Infrastructure Requirements

The following are issues to consider regarding the siting, installation, and operation of an avian radar system.

- Size
  - How big is the system (or its various components) and how much does it/they weigh?
  - Are the size and weight compatible with the planned location of the system?
- Enclosures: Which components …
  - Can be located outdoors in an unprotected environment?
  - Must be sheltered (outdoors, but protected)?
  - Must be enclosed (indoors, with temperature and humidity control)?
- How much electrical power will the system require?
- Connectivity
  - What are the network connectivity requirements of the system?
  - Does it require wired connections to a network, or will wireless connectivity suffice (see Section 3.4.4)?
  - Are there frequency spectrum issues with the wireless connections do (see Section 3.1.1)?
  - What are the network security (see Section 3.4.8) and information assurance (see Section 3.8.1) requirements?

4. References

Brand, Marissa. 2011. Integration and Validation of Avian Radars. Final Report, ESTCP Project RC-200723, April, 2011.

5. Points of Contacts

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